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MULTIPLE GOALS IN DYNAMIC DECISION
MAKING: AN EXPERIMENTAL APPROACH

by

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Leaders in both the military and civilian sectors make a series of interrelated decisions in real time to achieve goals. These decisions involve the allocation of resources, such as ships and aircraft to influence the situation facing the decision maker. NEWFIRE is a computer-based simulation of a forest fire fighting task that allows the experimenter to control both the goals and the environment in which the decisions are made and thereby explore the effects these variables have on the decision maker.

The objective of this thesis was to use the NEWFIRE microworld to determine the effects that multiple goals and system complexity have on decisions. Specifically, subjects were given one, two or three goals, and confronted with three scenarios of varying complexity. The results show that subjects given only one objective outperformed those given two or three objectives. The results also show that the performance of subjects on the most complex scenario was worse than on the less complex scenarios.

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Multiple Goals in Dynamic Decision Making: An Experimental Approach

by

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ABSTRACT

Leaders in both the military and civilian sectors make a series of interrelated decisions in real time to achieve goals. These decisions involve the allocation of resources, such as ships and aircraft to influence the situation facing the decision maker. NEWFIRE is a computer-based simulation of a forest fire fighting task that allows the experimenter to control both the goals and the environment in which the decisions are made and thereby explore the effects these variables have on the decision maker.

The objective of this thesis was to use the NEWFIRE microworld to determine the effects that multiple goals and system complexity have on decisions. Specifically, subjects were given one, two or three goals, and confronted with three scenarios of varying complexity. The results show that subjects given only one objective outperformed those given two or three objectives. The results also show that the performance of subjects on the most complex scenario was worse than on the less complex scenarios.

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I. INTRODUCTION

A. RESEARCH QUESTION

Individuals make decisions for the purpose of achieving some goal (Brehmer, 1992; Hogarth, 1981). Whether that goal is as mundane as preparing a meal or as critical as winning a naval engagement, a series of interrelated decisions is required. These decisions must be made in real time in an environment that changes of its own accord as well as in response to the decisions made (Brehmer, 1992; Sengupta and Abdel-Hamid, 1992). Typically, laboratory studies have tended to frame decision making in static contexts (Hogarth, 1981).

Brehmer (1992) suggests the use of microworlds as an effective means to investigate the continuous nature of decision making in complex dynamic environments. A microworld is an interactive computer-based simulation. An example of a microworld based on a forest fire fighting task is NEWFIRE (Loevborg and Brehmer, 1991). Brehmer (1992, p. 238) argues that the results of experiments conducted thus far with microworlds "...may express some generally valid characteristics of people trying to control complex dynamic systems."

Microworlds have been used to address issues of cognitive heuristics and feedback strategies (Kleinmuntz,

1985), complexity of the environment (Mackinnon and Wearing, 1980), decision strategies (Kleinmuntz and Kleinmuntz, 1981), learning the time constants of a task (Brehmer et al., 1992a) and incorporating cost information in decision making (Brehmer et al., 1992b). Brehmer (1992) notes that goal conflicts seldom appeared in these experiments. Therefore, while the results are generally indicative of the subjects' mental models, an important aspect of decision making still needs to be incorporated into the research (Brehmer, 1992).

This thesis employs NEWFIRE to address the following research question: **How does the number of goals affect the quality of decision making in complex dynamic environments under different levels of task complexity?**

B. HYPOTHESES

Two primary hypotheses guide the research question. The first hypothesis concerns the relationship between the number of goals a decision maker is attempting to meet and the quality of decisions he/she makes. Because some goals may conflict with each other and because the process of tracking progress toward more than one goal is cognitively more challenging, subjects given more goals should make decisions of lesser quality than those given fewer goals. Decisions of poorer quality should generally lead to worse

performance. Thus the first hypothesis is: **Subjects receiving one goal will perform better than subjects receiving two goals, who will perform better than subjects receiving three goals.**

The second hypothesis concerns the relationship between the complexity of the task and the quality of decisions made in the completion of that task. Complexity in NEWFIRE arises from the number of fires, the wind direction and velocity, and the efficacies of the fire fighting units. These characteristics have been incorporated in three experimental scenarios, labelled as easy, moderate and difficult. These scenarios are described in detail in Chapter III and Appendix A. Lesser complexity means fewer elements and fewer interactions that must be considered by the decision maker. It is therefore reasonable to expect that subjects would perform better on the cognitively easier, less complex tasks. The second hypothesis is: **Subjects will perform better in the easy scenario than in the moderate scenario, and better in the moderate scenario than in the difficult scenario.**

II. THEORETICAL PREMISE

A. DYNAMIC DECISION ENVIRONMENTS

The private, public and government organizations in which individuals must make decisions are complex, and that complexity is growing (Mackinnon and Wearing, 1980). Mackinnon and Wearing (1980) note that this complexity primarily stems from three sources:

1. the number of elements,
2. the degree of interaction among those elements, and
3. the degree to which uncertainty influences the system.

The decisions individuals must make are also dynamic in nature (Sengupta and Abdel-Hamid, 1992). Decision makers must make decisions in response to the demands of the environment. An individual cannot make decisions only when he/she feels ready to do so (Brehmer, 1992).

Medical decision making is a good example (Kleinmuntz and Kleinmuntz, 1981). The goal of the physician is to diagnose and cure the patient. The physician must examine the patient and determine what symptoms are present and what disease or conditions they indicate. The physician must make a decision as to what treatment to prescribe. The physician then monitors the condition of the patient and make a series of decisions as to whether to continue the current treatment, change to another, or simply stop

treatment. The decisions are not independent, that is treatment prescribed in previous periods will affect the current decision and may have side-effects which induce other symptoms or conditions. Two medications may counter each other's effects. The state of the patient's health changes autonomously as a result of the disease and also as a result of the treatment. These decisions must be made in real time. A physician cannot keep a dying patient waiting while he/she thinks the problem over at length.

In a military context, the Tactical Action Officer (TAO) standing watch in the Combat Information Center (CIC) of a warship is operating in a complex dynamic decision making environment. His goal is to fight the ship, that is, in essence to destroy the enemy, and prevent any damage to his own ship. He takes information from ship's sensors to classify contacts as friendly, hostile or neutral. He must decide what actions to take to protect his ship. He can attempt to warn them off, destroy them, interfere with their ability to attack him or simply keep a watchful eye on them. The disposition of these other forces will change autonomously according to their own operational plan. In addition, the TAO's actions will draw a reaction from them. For instance, illuminating an aircraft with a fire control radar is considered to be a hostile act, and will most likely either cause the aircraft to withdraw or attack.

All of these dynamic decision situations embody four common characteristics (Brehmer, 1992). First, a series of decisions is required to reach the goal. Both the physician and the TAO must continuously monitor the situation and iteratively decide what action, if any, to take. Second, the decisions are not independent. A medication may produce side effects. If the TAO ceases radar emissions to avoid detection by a hostile force, he forgoes the ability to detect that force beyond visual range. Also any missile he fires at one contact cannot be fired at another. Third, the state of the problem changes, both autonomously and as a result of the decisions. Both a disease and a hostile force will progress on their own, changing the situation. However, the situation is also altered by the actions of the physician or TAO. Fourth, the decisions must be made in real time. Hesitation in both the medical and military communities can carry drastic penalties. It is a fact of life that time waits for no one.

Thus, individuals make many decisions in complex dynamic environments. What factors influence the quality of these decisions is therefore of importance. However, as Hogarth (1981) and Brehmer (1992) point out, much of the research in decision making has been conducted in static contexts, whereas, individuals must operate in dynamic decision situations.

B. EXPERIMENTAL METHODOLOGY

1. Conceptual Basis

Decisions are made not for their own sake, but to achieve control of the system (Brehmer, 1992), enabling some desirable condition to be achieved or maintained (Brehmer, 1992; Hogarth, 1981). Brehmer (1992, p. 217) has identified four general conditions for control of a system.

- there must be a goal (the goal condition),
- it must be possible to ascertain the state of the system (the observability condition),
- it must be possible to affect the state of the system (the action condition),
- there must be a model of the system (the model condition).

The observability and action conditions are properties of the system. The goal and model are properties of the decision maker. Decision makers form their goals and model based on the observability and action conditions presented to them (Brehmer, 1992). It is this translation of observability and actions into goals and models that is of interest.

Feedback is critical to the formulation of mental models. Various feedback strategies may be employed. In outcome feedback control, only information about the current situation is used to determine an action. This strategy works well in the absence of feedback delays (Brehmer, 1992; Sengupta, 1992). In feedforward control, a model developed prior to beginning the task is used to predict the actual state of the system, and what actions are required to

achieve or maintain a desired state. This requires that the system must not change significantly over time, because changes would invalidate the model (Brehmer, 1992; Sengupta and Abdel-Hamid, 1992).

The feedback strategy of the decision maker determines the kind of model needed (Brehmer, 1992). Brehmer (1992) continues on to emphasize the need for an experimental paradigm that allows the observability and action possibilities to be defined in such a way that the subject's goals and mental models can be inferred. (Brehmer, 1992)

2. Methodological Basis

Field studies of dynamic decision making are hampered by the complexity of most real world systems (Brehmer, 1992). It is difficult if not impossible for the experimenter to develop a realistic model of the tasks. The effects of environmental noise are difficult to gauge. That is, the experimenter is hampered by opaqueness as much as the subjects.

Therefore, microworlds have been introduced to study dynamic decision making. A microworld is a computer based dynamic simulation with which subjects interact. Numerous studies have already used microworlds of welfare administration (Mackinnon and Wearing, 1980), medical treatment (Kleinmuntz and Kleinmuntz, 1981), forest fire fighting (Loevborg and Brehmer, 1992; Brehmer et al., 1992a;

Brehmer et al., 1992b).

An example of a computer simulated microworld is NEWFIRE (Loevborg and Brehmer, 1991), in which subjects act as the commander of a forest fire fighting force. NEWFIRE incorporates the four characteristics of dynamic decision making. A series of commands to fire fighting units (decisions) is required to combat the forest fires, as the fires can rarely be extinguished in one time period by one unit. The decisions are interrelated since once a unit has begun fighting a fire in one location, it must extinguish that fire completely before it can be dispatched to another area. The state of the fire changes autonomously as a result of wind and the algorithm that propagates the fire. Because locations where fire has been extinguished or burned out on its own cannot re-ignite, the actions of the fire fighting units, determined by the commander, also alter the state of the fire(s). Decisions must be made in real time because the NEWFIRE simulation is controlled by the computer's clock. The simulation does not halt and wait for the commander to input his/her commands (Loevborg and Brehmer, 1992).

NEWFIRE also meets Brehmer's (1992) four general conditions for control of a system. The goal is to extinguish the forest fires. Through reports from the spotter plane and fire fighting units, the state of the system can be ascertained. The state of the system is

affected by the ordering of units to fight fires. Subjects are able to develop a mental model of how the fire propagates and how the fire fighting units affect it.

C. PRIOR RESEARCH

Several studies in decision making have already been conducted using microworlds. These have tended to focus on feedback (observability) and the formation of mental models (model) by studying the actions of decision makers. Microworlds have been used to simulate a forest fire fighting task (Loevborg and Brehmer, 1991; Brehmer et al., 1992a; Brehmer et al., 1992b), medical treatment (Kleinmuntz and Kleinmuntz, 1981; Kleinmuntz, 1985) and welfare administration project (Mackinnon and Wearing, 1980). However, the results of these experiments are generally representative only of the characteristics of the subjects' mental models. Very few conflicting goals have been present in the tasks studied thus far (Brehmer, 1992). To that end, Loevborg and Brehmer (1991) have introduced a version of NEWFIRE, a forest fire fighting simulation. This is a microworld which allows the experimenter to use cost factors to examine the effects of multiple conflicting goals.

NEWFIRE's usefulness as an experimental tool has been shown in several studies (Brehmer et al., 1992a; Loevborg and Brehmer, 1992; Brehmer et al., 1992b). Brehmer, Loevborg and Winman (1992a) have used it to investigate how subjects' learn the time constants of a task. Marsden and

Reason, and later Irmer and Reason, have studied subjects' initial adaptation to a task (Loevborg and Brehmer, 1992). Brehmer, Loevborg and Winman (1992b) have used NEWFIRE to examine the effects of costs in a dynamic decision environment. In this latest study, goals were explicitly studied.

In two experiments, Brehmer, Loevborg and Winman (1992b) have used fairly simple scenarios where the fire can be extinguished quickly and with few resources. Each scenario lasted on average about four to six minutes. The test scenarios involved only one ignition, of either a "close fire" or a "distant fire". A "close fire" is one whose ignition occurs one or two cells from the initial location of a fire fighting unit, and can be extinguished by only one unit. A "distant fire" is an ignition five or six cells from the initial location of a fire fighting unit, and can be extinguished by a minimum of four fire fighting units. The number of units mentioned here is optimal. Delays in the initial reaction to an ignition, or in the case of a distant fire dispatching too few units, would allow the fire to grow. More resources would then have to be used to put out the fire. (Brehmer et al., 1992b)

The first of these two experiments involved three experimental conditions. The control group was given no cost information. One experimental group was given information about costs. The other experimental group

received cost information, and a display of the cumulative costs incurred while performing the fire fighting task. Both experimental groups were told to fight the fires as economically as possible, while preserving the base. In effect they were given two goals. The results showed that those given a cumulative cost display performed worse than those who were only told to consider cost. Both experimental groups performed worse than the control group. (Brehmer et al., 1992b)

The second experiment sought to determine if the cost goal hindered performance or simply learning. To distinguish whether the cost goal affected performance or learning, subjects learned the task by practicing NEWFIRE without any knowledge of costs. They were divided into an experimental group which was informed of costs, and a control group which was not. The results suggested that the additional goal of minimizing costs hampered learning, not performance. That fear of poor cost performance induced risk-averse behavior is presumed to be the cause of these findings. (Brehmer, et al., 1992)

This thesis intends to further this work examining how subjects handle a number of goals. We also increased the complexity and difficulty of the tasks, thereby necessitating a longer series of decisions. Thus, the scenarios employed here last longer. Subjects typically complete five scenarios in one to one and a half hours,

compared to sixteen scenarios in the same time period in the Brehmer and Loevborg (Brehmer et al., 1992a; Brehmer et al., 1992b) experiments. By studying a longer duration of dynamic decisions, it is hoped that insight may be gained into some longer term impacts of a series of interrelated decisions.

D. EXPECTED RESULTS

It would be expected that as the number of goals and the task complexity increase, the quality of decisions will decrease. Individuals have severe limits on their ability to process information, and therefore complexity in the environment should degrade the performance of the individual in decision making (MacKinnon and Wearing, 1980).

Task complexity, in NEWFIRE, is found in the number of fires, the distance between the fire and the nearest fire fighting unit, the efficacies of the fire fighting unit and the direction and velocity of the wind, which affects the propagation of the fire. It is reasonable to expect that increasing the complexity will decrease the quality of the decision maker's performance (MacKinnon and Wearing, 1980). One probably will not fight two fires as easily as one, and the farther away the fire the more difficult it will be to extinguish. This is because while the units are travelling to the fire, it will have time to spread and intensify. Similarly, a strong wind will fan the flames, spreading the fire more quickly.

A greater number of goals would also be expected to degrade performance. With only one goal, the decision maker can work with a model that is biased toward that aspect of the system. Since this is a greatly simplified version of reality, it is also cognitively easier to manipulate, thereby yielding improved performance. But with two goals to consider, the model becomes more complex. Additional aspects of the environment that pertain to the achievement of the second goal must now be entered into the model. More elements and more interaction among the elements add to the complexity of the model. This model is no longer as simple to use, and as a consequence performance will suffer. Consider the decision of how many fire fighting units to dispatch to an ignition. If the only goal is to minimize the amount of forest lost to fire, it would be wise to respond with more units than actually believed necessary. The additional units provide a safety margin with little or no detrimental effect on achieving the goal. But if costs are also to be minimized, then the decision maker is penalized for sending any more units than are actually needed. The tendency in this second case, with two goals is to not dispatch a unit unless it's presence is vital to extinguishing the blaze (Loevborg and Brehmer, 1992).

Besides the added complexity, multiple goals may sometimes conflict with each other. To do well in pursuit of one goal may require sacrificing progress toward another

goal. For instance, consider a fire that is completely encircled by ash, but is still burning inside. With only one goal of minimizing area lost to fire, the decision to send units into the fire to preserve what little forest remains is fairly straight forward. However if the decision maker is also attempting to minimize costs (conserve resources) the decision is not at all simple. The fire cannot spread beyond the surrounding wall ash, so the decision to attack the fire, while reducing potential lost area, increases costs. On the other hand, not incurring the cost of fighting that fire means more area burned (Brehmer et al., 1992b).

People would be expected, due to limits of cognitive abilities, to concentrate on achievable goals, to the extent they are not failing too terribly in achieving another goal. It is expected that some goal shifting would occur. That is, when a subject realizes he/she is progressing poorly toward one goal, (for instance, minimizing the amount of forest burned) while still within reach of another goal (minimizing costs), they will make decisions that favor the first goal over the latter. Once (re)gaining control of progress towards the second goal, subjects would likely continue paying closer attention to that goal, until it appears that the first goal will not be met. Thus subjects are expected to shift attention between goals, but generally

only when prompted to do so by diminishing prospects of achieving one or another goal.

III. METHODOLOGY

A. TASK ENVIRONMENT

NEWFIRE (Loevborg and Brehmer, 1991) is a microworld designed to simulate a forest-fire fighting environment. Loevborg and Brehmer (1991) describe the NEWFIRE environment. Figure 1 shows the NEWFIRE screen. The forest area is represented to the left by a large green square, divided into an 18 x 18 grid. Each grid coordinate can be identified by column, numbered 1 through 18 from left to right (East to West), and row, lettered A through R from top to bottom (North to South). Each cell represents 1 hectare of forest. The base camp appears as a brown cell and is denoted by a 'B'. Eight individual fire fighting units (FFU) appear as light blue numbered squares. A fire appears as a red cell(s) in the forest grid.

The subject, acting as commander of the eight fire fighting units, orders them to the fire. The icon for an individual fire fighting unit changes color to suit its task. While inactive, or watching for a fire the icon is light blue. When the unit begins travelling to its ordered destination, it changes color to purple, and a small purple number corresponding to that unit appears in the upper left corner of the destination cell. The fire fighting unit turns dark blue when engaged in a fire fighting operation.

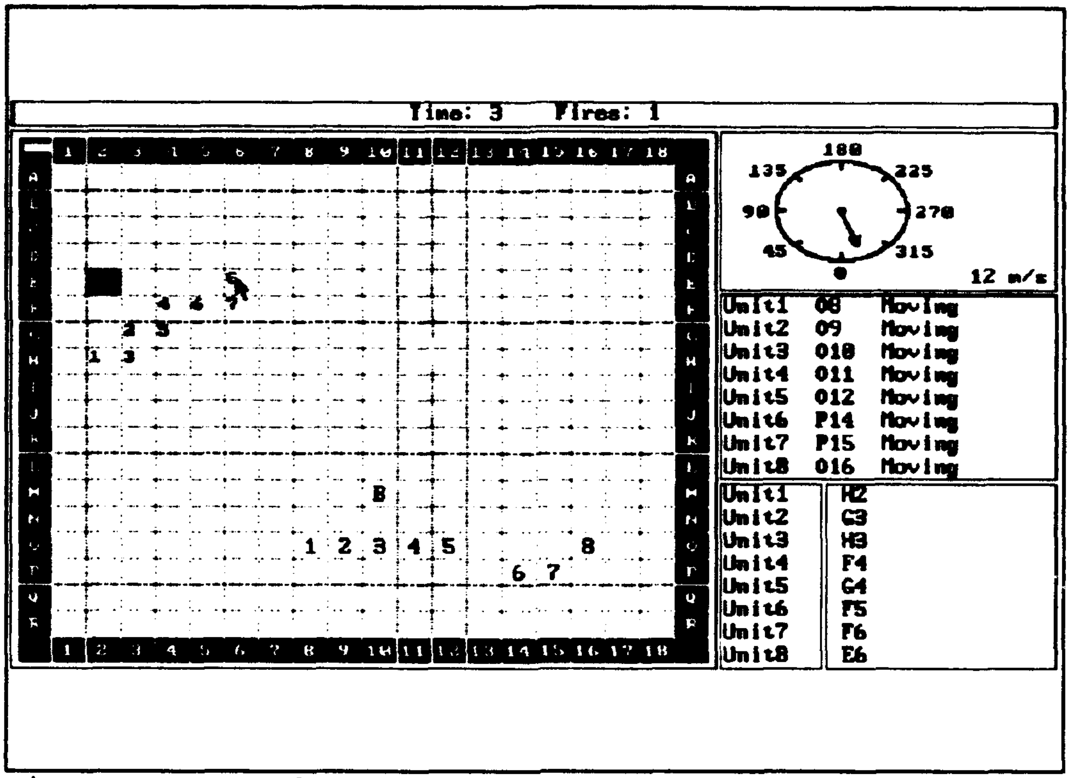

Figure 1. Sample NEWFIRE Screen

The activity information and current location of each fire fighting unit is displayed in brief text in the message panel, the middle window on the right hand side of the screen. The lower right hand panel displays each fire fighting unit's number and its ordered destination, if any.

The wind direction and velocity are displayed in the upper right hand corner. The arrow points downwind, and the numbers around the compass are reversed, so that a heading indicated by the arrow head is the direction from which the wind blows. Wind velocity is given as a number in meters per second.

Cumulative time, forest area burned and costs (if applicable) are displayed in the banner across the top of the screen.

Each fire fighting unit operates semi-autonomously. They rely on the commander to deploy them, but once given an order they will carry it out without any further guidance. All units begin the simulation inactive, and become active when given an order to move. They travel in a straight-line to their destination. The cells are large enough that they can safely traverse through a burning cell. An fire fighting unit can be given a destination at any time. If it is inactive or watching, it will immediately begin travelling to the destination. If it is already travelling, it ignores the previous destination and begins travelling immediately to the most recent destination. If the unit is engaged in a fire fighting operation it will finish that operation but, upon completion, will automatically travel to the destination it was most recently given.

When a fire fighting unit arrives at its destination, its actions are determined by the state of that cell. If the cell is unburned forest, the unit watches for a fire. If the cell is burnt forest, the unit perceives this as a parking maneuver and becomes inactive. If the cell is burning, the unit begins its fire fighting operation. The first step is mobilizing, that is, it unpacks its equipment from the vehicle. It then fights the fire, and when the

fire has been extinguished, it demobilizes, packing its equipment in preparation for its next move. If the fire fighting unit has not received an order by the time it finishes demobilizing, it will remain in place, becoming inactive.

B. SIMULATION MODEL

The spread of the fire is controlled by a cellular automaton. Left alone, the fire in a cell will burn itself out 15 time units after catching fire. Within each cell, the intensity of the fire increases linearly to time 7.5 and then decreases linearly after that. Since the process of fighting the fire is itself also linear, a fire fighting unit will extinguish a "young" or "old" fire in appreciably less time than a "middle-aged" fire. (Loevborg and Brehmer, 1991) This is illustrated in Figure 2 (Loevborg and Brehmer, 1991, p. 32).

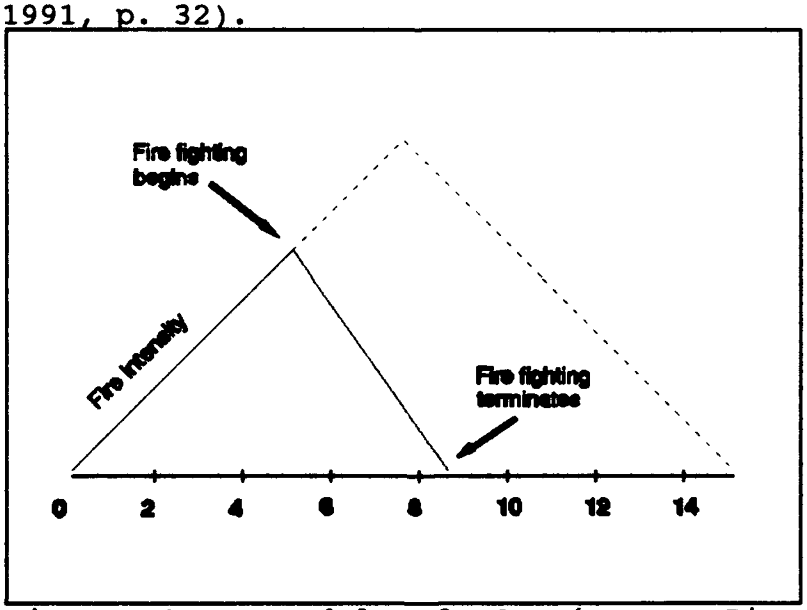

Figure 2. Model of Continuous Fire Fighting

The fire spreads throughout the forest in the shape of an ellipse with an axis parallel to the wind. The higher the velocity of the wind, the more narrow and elongated will be the fire's footprint. (Loevborg and Brehmer, 1991)

Once the fire in a particular cell has been extinguished or burned out on its own, that cell cannot re-ignite, even if only a very small portion of the cell has actually burned. Thus, by fighting only the leading edge of the fire, a wall can be created to prevent further spread of the fire. (Loevborg and Brehmer, 1991) This characteristic can be very helpful to the subject, but can also be a hindrance. As Ketscher (1992) noted, the elliptical pattern of the fire's spread is obscured, and interferes with the subjects' ability to form a mental model of fire propagation.

C. EXPERIMENTAL DESIGN

The research design is illustrated in Table 1. The experiment used a factorial design with two components to capture the number of objectives and the task difficulty. The number of objectives was operationalized as a between subjects condition and the task difficulty as a within subjects condition.

Table 1. EXPERIMENTAL DESIGN. Number of subjects per group.

Order of Scenarios	Number of Objectives Group		
	One	Two	Three
Order 1 (D, M, E)	9	9	9
Order 2 (E, D, M)	9	9	9
Order 3 (M, E, D)	9	9	9

Randomization of within subjects conditions was achieved using a Latin Squares design as follows (Kirk, 1982, pp. 311-312):

First, each task was assigned a corresponding letter.

E: Easy

M: Moderate

D: Difficult

Next, two sequences of random numbers were generated.

(3, 1, 2)

(1, 3, 2)

The square is then selected.

E	M	D
M	D	E
D	E	M

Rows are then arranged according to the first set of random numbers.

```
D  E  M
E  M  D
M  D  E
```

Columns are then arranged according to the second set of random numbers.

```
D  M  E
E  D  M
M  E  D
```

Finally each group is assigned to one these orders as below:

Group 1: D, M, E
Group 2: E, D, M
Group 3: M, E, D

Thus, Group 1 conducts tasks in the order: Difficult, Moderate and Easy.

1. Between-Subjects

The fundamental objective of this experiment is to determine the effect of varying levels of system complexity on decision making in dynamic environments. The goals given to subjects constituted the three between-subjects conditions. The predominant goal of all groups was to preserve the base. One group was told only to minimize the area of forest burned by the fire. The second group was given two goals, to minimize the area burned and to minimize the costs incurred while fighting the fire. The third group was given three goals, minimize the area burned, costs incurred and the time taken to extinguish the fire. The

order that the objectives were presented to subjects was randomized within the two and three objective groups.

2. Within-Subjects

In addition, the experiment sought to capture the effects within each condition over time. In this experiment each subject performed three scenarios, an easy, a moderate and a difficult one. The differences between the scenarios are summarized in Table 2. The easy scenario involved only one ignition. Wind velocity and direction were held constant throughout. All fire fighting units were homogeneous; that is, every unit had the same moving speed and put-out speed as every other unit. In the moderate scenario, a second fire was ignited at time 6 in a cell relatively close to the first ignition. Wind direction remained constant, but the speed changed. All fire fighting units were homogeneous. In the difficult scenario, a second fire was ignited at time 6 in a cell distant from the first ignition. Both wind direction and velocity vary

TABLE 2. SCENARIO SUMMARY

		EASY	MODERATE	DIFFICULT
No. of ignitions		1	2	2
WIND	Direction	Constant (000)	Constant (270)	Changes (135 to 045)
WIND	Velocity	Constant (10 m/s)	Changes (18 to 6 m/s)	Changes (4 to 18 m/s)
Homogeneous FFU's ?		Yes	Yes	No

significantly, but only once. Four of the fire fighting units are half as effective (in both moving speed and put-out speed) as the other four.

Thus, the moderate scenario is more complex than the easy scenario by increasing the number of separate ignitions from one to two, and by reducing wind velocity during the fire fighting. The complexity added by the second ignition is obvious. By reducing the wind velocity but not direction, the pattern of fire propagation changes from a narrow ellipse stretched in the direction of the wind to more rounded, almost circular shape.

The difficult scenario is made progressively more complex by changing both wind direction and velocity, and by the fact that the fire fighting units are not of equal abilities. Shifting the wind direction changes the direction in which the fire tends to spread. The increase in wind velocity narrows the elliptical pattern of the fire and increases the speed with which it spreads to neighboring downwind cells. Only four of the eight fire fighting units are as effective, in terms of moving speed and put out speed, as the units in the easy and moderate scenarios. The other four units are half as effective. These travel only half as fast and put out fires at half the rate of the more effective units.

3. Subjects

The experiment was conducted using 81 graduate students. Participant profiles are contained in Table 3. Participants were divided into nine cells based on objective functions and task order.

A random stream of two digit numbers was generated using a random number table. Duplicates and numbers greater than 81 were disregarded. Each subject was assigned the subsequent number in that stream, based on the order he/she arrived. Random arrival of subjects was assumed.

D. EXPERIMENTAL CONDUCT

The experiment was conducted in a computer lab with the same attendant present for the duration of all trials. Subjects were given time to read the documentation. Subjects' questions regarding manipulation of the interface, asked either before or during the trial were answered. Questions pertaining to strategy in performing the task were not permitted.

TABLE 3. Participant Profiles (Means)

	N	Mean Value
Age	81	33.222
Years of work experience	81	12.407
Years since completing undergrad	81	10.037

The simulation was run in a computer lab using a single personal computer, with a 387 math co-processor. Only one subject performed the experiment at one time.

All subjects performed a mouse practice exercise, and one or two practice scenarios before beginning the actual experiment, where they received different types of information concerning their goals. The steps performed by each group are summarized in Table 4.

1. Mouse Practice

The purpose of the mouse practice facility in NEWFIRE is to ensure all subjects possess a requisite level of dexterity with the mouse, thereby eliminating the noise of mouse manipulation difficulties from the experiment result (Loevborg and Brehmer, 1992). These difficulties arise from one of two sources. First, some subjects rarely or never use a mouse. Second, the "speed" of the mouse, i.e. ratio of mouse movement to cursor movement, is not often different from that which experienced mouse users are accustomed to on their own computers.

Operating instructions for the mouse practice facility were read by the subject, and any questions were answered. These instructions are provided in Appendix B. The mouse practice facility presents the subject with two grids. Blue icons appear at varying intervals in random squares in the grid to the left. The subject uses the mouse to move those icons to the grid on the right.

2. Practice Scenarios

After completion of the mouse practice, subjects read the instructions for the NEWFIRE environment, included in Appendix C. The first twenty-five subjects then performed one practice scenario, described in Appendix A, before beginning the experiment. This one practice did not provide subjects with sufficient opportunity to learn how to operate NEWFIRE and develop a mental model of the task. The remaining subjects therefore also performed an additional, more difficult practice scenario, described in Appendix A.

3. Experiment Scenarios

Information on goals was provided to subjects as appropriate to their experimental conditions. Subjects receiving cost information also received the budget information for each task immediately before beginning that task. These documents are shown in Appendix D. Each subject performed three tasks, detailed in Appendix A.

4. Questionnaire

After completing the experiment, subjects filled a questionnaire, appropriate to their between subjects condition. All three questionnaires contained the same core questions, but groups receiving two objectives and three objectives were asked additional questions pertaining specifically to cost and other goals. The questions asked are contained in Appendix E.

TABLE 4. Sequence of Experiment.

Subjects' Actions	Order of Actions		
	One Objective Group	Two Objectives Group	Three Objectives Group
Read mouse instructions	1	1	1
Perform mouse practice	2	2	2
Read NEWFIRE instructions	3	3	3
Perform practice scenarios	4	4	4
Read Cost Information	N/A	5	5
Read first scenario budget information	N/A	6	6
Perform first scenario	5	7	7
Read second scenario budget information	N/A	8	8
Perform second scenario	6	9	9
Read third scenario budget information	N/A	10	10
Perform third scenario	7	11	11
Fill out questionnaire	8	12	12

E. RESULTS

The experiment utilized 81 participants. The results of nine subjects were discarded for the following reasons. Two subjects failed to complete the scenarios due to a hardware malfunction. Four subjects lost the base, and therefore their results were discarded. Two subjects' performances exceeded more than two standard deviations from the mean. Results of one subject were discarded due to a procedural error by the experimenter. Therefore the results of 72 subjects were analyzed. Figures 3 through 5 show the performance between subjects and within subjects, measured by cost, area and time burned.

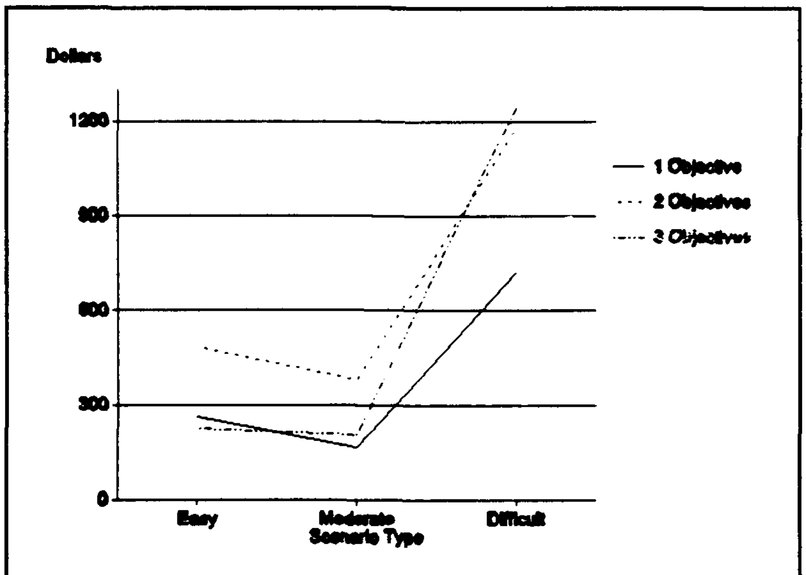

Figure 3. Mean Costs

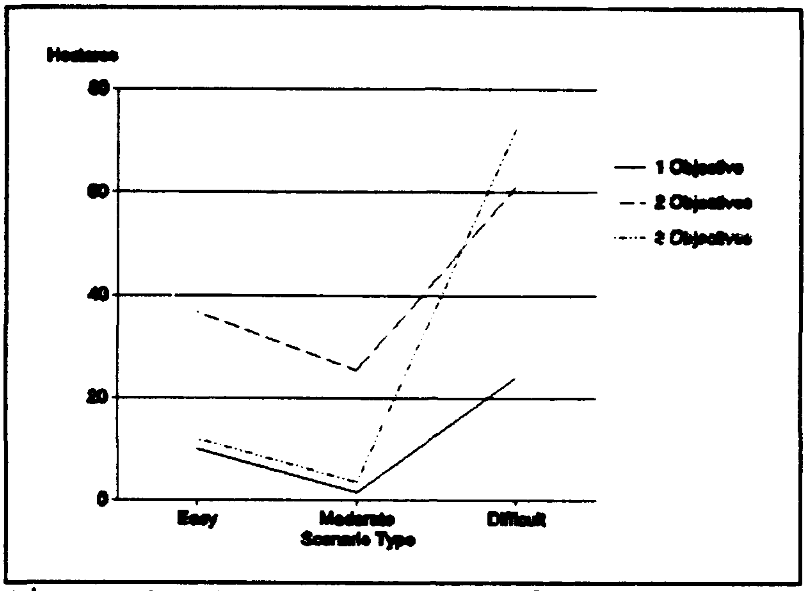

Figure 4. Mean Areas Burned

The hypotheses were tested by applying the following analysis of variance (ANOVA) model for multiple Latin Squares, as suggested by Winer (1971, p.697):

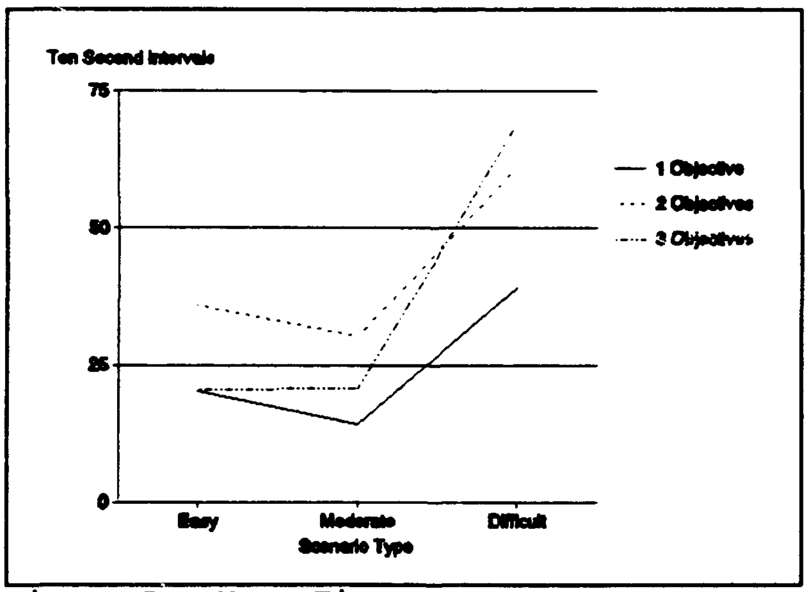

Figure 5. Mean Times

$Y_{ij}m = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + e_{ijm}$ where:

μ is constant,

α_i is the number of objectives group (i = 1, 2, 3, where 1 = one objective, 2 = two objectives, and 3 = three objectives),

β_j is the type of scenario (j = 1, 2, 3, where 1 = easy, 2 = moderate, and 3 = difficult),

e_{ijm} is the experimental error term.

TABLE 5. ANALYSIS OF VARIANCE. Dependent Variable: Cost.

Source of Variance	S. S.	Degrees of Freedom	F-Value	P	R-Square
Model	33610699.750	8	16.22	0.0001	0.385373
Group	3268012.333	2	6.31	0.0022	
Scenario	28101940.750	2	54.26	0.0001	
Group* Scenario	2240746.667	4	2.16	0.0744	
Subjects	53605286.083	207			

The analysis followed the General Linear Models procedure (SAS, 1987). The ANOVA results, contained in Tables 5 through 7, reveal that the performance of subjects across the three different objective conditions was significantly different for the three dependent variables, cost (F=6.31, p=0.0001), area (F=7.36, p=0.0008) and time (F=8.45, p=0.0003). Therefore the null hypothesis of no significant

TABLE 6. ANALYSIS OF VARIANCE. Dependent Variable: Area.

Source of Variance	S. S.	Degrees of Freedom	F-Value	P	R-Square
Model	120649.19467	8	7.17	0.0001	0.216869
Group	30976.548548	2	7.36	0.0008	
Scenario	71050.695626	2	16.88	0.0001	
Group* Scenario	18621.950494	4	2.21	0.0689	
Subjects	435673.74859	207			

differences among number of objectives condition is rejected. The results indicate that the subjects' performance was influenced by the number of objectives they attempted to satisfy.

Additionally, Tables 5 through 7 show that the performance within subjects was significantly different depending on the complexity of the scenario they faced in

TABLE 7. ANALYSIS OF VARIANCE. Dependent Variable: Time.

Source of Variance	S. S.	Degrees of Freedom	F-Value	P	R-Square
Model	70719.148148	8	12.42	0.0001	0.324311
Group	12036.148148	2	8.45	0.0003	
Scenario	52207.814815	2	36.67	0.0001	
Group* Scenario	6475.185185	4	2.27	0.0625	
Subjects	147340.291667	207			

terms of cost ($F=54.26$, $p=0.0001$), area ($F=16.88$, $p=0.0001$) and time ($F=36.67$, $p=0.0001$). Therefore the null hypothesis of no significant differences in performance depending on the complexity of the scenario is also rejected.

Posterior tests using Scheffe's method confirm that for the three dependent variables, there were significant differences between the groups receiving different numbers of objectives. The mean values of cost, area, and time of the group given one objective were significantly lower than the values for the groups given two or three objectives ($p<0.05$). This supports the first hypothesis that subjects given only one objective to accomplish will perform better. However, there was no significant difference in performance between the group receiving two objectives and the group receiving three objectives.

Additionally, posterior tests show that for the three dependent variables significant differences of performance exist between scenarios of different levels of complexity. In terms of cost, area, and time, subjects performed significantly worse on the most complex scenario than on the easy or moderate ($p<0.05$).

IV. CONCLUSIONS

A. SUMMARY OF RESULTS

The aim of this study was to investigate the effects of multiple objectives on the quality of decision making in complex dynamic environments under different levels of task complexity. NEWFIRE, a microworld simulating a forest fire fighting task was used. Chapter II described in general terms some of the research that has been done with microworlds (see also Funke, 1991), and pointed out that to date few studies have examined the effects of multiple, and possibly conflicting, objectives in a dynamic environment. Additionally, Chapter II explained that more goals create greater complexity in the system, which is cognitively more difficult for decision makers to manage. Thus one would expect that a larger number of goals assigned to a person will decrease the quality of decisions that person makes. Chapter II also discussed complexity arising from sources other than goals. This environmental complexity would also be expected to decrease the quality of decisions.

The results of this study support the hypotheses. Subjects given only one goal significantly outperformed those given two and three goals, and subjects performed better in the easy scenario than they did in the moderate and difficult scenarios.

B. ANALYSIS OF RESULTS

The results of this experiment clearly indicate that persons attempting to achieve only one goal perform better than those attempting to satisfy multiple goals. In Figures 3 through 5, the performance of the two goal group parallels the performance of the one goal group. This is also supported by the Scheffe posterior tests. However, the performance of the three goal group is puzzling. This group significantly outperformed the two goal group on the easy and moderate scenarios, but in the difficult scenario, performed worse than either other group.

One possible explanation for the anomalous behavior of the three goal group is the effects of goal shifting. It may be that the subjects in the three goal group adopted a strategy (perhaps unwittingly) of continually and rapidly shifting among goals, in effect sampling their progress. This pathology of decision making, termed 'thematic vagabonding' by Brehmer (1992), is evidenced by subjects shifting from one part of a problem to another, failing to adapt to the interdependencies in the environment. It is possible that this strategy is as effective in fairly simple tasks as concentrating continually on only one goal. However, it is possible that once task complexity increases beyond a threshold, the strategy of rapid and continuous goal shifting fails.

There was no significant difference between subjects'

performance in the easy scenario and their performance in the moderate scenario. Indeed, subjects performed slightly better on the moderate scenario than on the easy one. The most likely cause of this lies in the difficulties that subjects have forming a mental model of the fire propagation. Unless the wind velocity is high (typically 18 meters per second), the fire propagates upwind, albeit at a much slower rate than its downwind propagation. Subjects are often not prepared for this upwind movement of fire. This usually was not a problem in the moderate scenario because the initial wind speed is 18 meters per second, and thus does not spread upwind. By the time the wind velocity lessens, the upwind edge of the fire borders on burned cells, which cannot re-ignite.

C. LIMITING FACTORS TO GENERALIZABILITY

Is it reasonable to extend these findings to the real world? This question has two aspects, the use of graduate students as surrogates for decision makers and the applicability of the task environment.

All of the graduate students participating in this experiment are also experienced military officers. Few of the subjects have had any previous fire fighting experience. They are practiced in making decisions in their job specialties, such flying aircraft, driving ships, leading a company of infantry, etc. It can reasonably be inferred

that the subjects had little epistemic competence for the NEWFIRE task, but did possess adequate heuristic competence. It is therefore reasonable to assume their behavior in this experimental investigation is an adequate representation of their real world decision making.

Microworlds, such as NEWFIRE, have been used in numerous studies of aspects of cognitive heurisitics and dynamic decision making (Funke, 1991). Brehmer (1992) notes that experiments with microworlds have yielded some consistent results and that some of the results have been supported by the findings of field studies.

D. FURTHER RESEARCH

Based on the discussion of Section B above, future research is warranted to study the anomalies noted in the behavior of the three objective group. The experiment could be replicated using the preservation of the base as a third objective vice time. The scenarios could also be altered to take better advantage of the complexity the wind adds to the environment. NEWFIRE also allows for the inclusion of meadow, which does not burn, in the forest pattern. By placing ignitions in areas partially or totally enclosed by meadow, the trade-offs between area and cost become more evident.

Subjects in this experiment were given no information about the model of fire propagation, and had to develop

their own model as they performed the task. By providing this information, one might be able to separate the decision making process from the process of forming mental models. In other words, one might be able to distinguish between pathologies of decision making and pathologies of learning. This information might be provided in two ways. First by simply including an explanation in the instructions. Second, NEWFIRE has a facility that allows a completed scenario to be played back on the screen at an accelerated speed. It is therefore possible to show subjects examples of successful and unsuccessful strategies before they begin their trials.

Subjects were not told which fire fighting units were less effective in the difficult scenario. As a result, many simply ignored the difference and acted as if all were still homogeneous.

Other proposals for further research require some adaptations to NEWFIRE, with the requisite permission of Loevborg. Costs and wind velocity are currently displayed only as numbers. However, subjects tend to rely on iconic information and ignore text messages (Ketscher, 1992). By displaying costs in graphic form, say as a bar graph, and altering the length of the wind indicating arrow according to wind velocity, subjects might use that information as heavily as information already presented iconically.

Cost and area are difficult to balance against one another because they are measured in different units (dollars vs. hectares). By assigning dollar values to forest area and displaying the value of forest burned as well as area, subjects' decision making processes may become more clear. This could perhaps be made more sophisticated by varying the value of individual cells. For instance, a populated cell would be considered more valuable than an unpopulated one.

Given that dynamic decision environments are ubiquitous, the implications of how decision makers behave when faced with a series of interrelated decisions are equally widespread. Situations confronting decision makers rarely involve only one goal. The attainment of one goal often is interlaced with the attainment of other goals. For instance, for a commander to successfully attain the goal of landing an amphibious force, other goals must be attained, such as gaining air superiority and providing timely, accurate close ground support. These goals themselves may conflict. Does one devote resources to a strike against an airfield well inland, or use them against ground forces closer to the landing zone? How decision makers cope with these multiple goals and the complex dynamic environments in which they present themselves is an area of vital interest.

APPENDIX A

DETAILED DESCRIPTION OF SCENARIOS

A1 First practice scenario

Uniform forest
Base Location H10
Constant Wind
Initial Wind 315 @ 4 m/s
First Ignition location H6 at time T = 0
Age of fire when reported = 0
Cost Factors
Watching 1.00
Moving 2.00
Mobilizing, Demobilizing, Fighting 4.00
Clock Period = 10 seconds between updates

	Fire Fighting Unit Number							
	1	2	3	4	5	6	7	8
Starting Position	G9	G10	G11	H9	H11	I9	I10	I11
Moving Speed	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Put-out Speed	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5

A2 Second practice scenario

Uniform forest
Base Location G14
Constant Wind
Initial Wind 270 @ 8 m/s
First Ignition location J7 at time T = 0
Age of fire when reported = 0
Cost Factors
Watching 1.00
Moving 2.00
Mobilizing, Demobilizing, Fighting 4.00
Clock Period = 10 seconds between updates

	Fire Fighting Unit Number							
	1	2	3	4	5	6	7	8
Starting Position	F13	F14	F15	G13	G15	H13	H14	H15
Moving Speed	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Put-out Speed	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5

A3 Easy scenario

Uniform forest
Base Location M14
Constant Wind
  Initial Wind 180 @ 10 m/s
First Ignition location M6 at time T = 0
Age of fire when reported = 0
Cost Factors
    Watching 1.00
    Moving 2.00
    Mobilizing, Demobilizing, Fighting 4.00
Clock Period = 10 seconds between updates

	Fire Fighting Unit Number							
	1	2	3	4	5	6	7	8
Starting Position	L13	L14	L15	M13	M15	N13	N14	N15
Moving Speed	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Put-out Speed	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5

A4 Moderate scenario

Uniform forest
Base Location N5
Variable Wind
  Initial Wind 090 @ 18 m/s
  New Wind 091 @ 6 m/s
  Time of Shift T = 8
  Rate of Shift 2
First Ignition location H10 at time T = 0
Second Ignition location K12 at time T = 5
Age of fire when reported = 0
Cost Factors
    Watching 1.00
    Moving 2.00
    Mobilizing, Demobilizing, Fighting 4.00
Clock Period = 10 seconds between updates

	Fire Fighting Unit Number							
	1	2	3	4	5	6	7	8
Starting Position	M4	M5	M6	N4	N6	O4	O5	O6
Moving Speed	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Put-out Speed	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5

A5 Difficult scenario

Uniform forest
Base Location F6
Variable Wind
  Initial Wind 315 @ 4 m/s
  New Wind 225 @ 18 m/s
  Time of Shift T = 6
  Rate of Shift 5
First Ignition location F14 at time T = 0
Second Ignition location O6 at time T = 5
Age of fire when reported = 0
Cost Factors
    Watching 1.00
    Moving 2.00
    Mobilizing, Demobilizing, Fighting 4.00
Clock Period = 10 seconds between updates

	Fire Fighting Unit Number							
	1	2	3	4	5	6	7	8
Starting Position	E5	E6	E7	F5	F7	G5	G6	G7
Moving Speed	1.1	2.0	1.1	1.1	2.0	2.0	1.1	2.0
Put-out Speed	0.25	0.5	0.25	0.25	0.5	0.5	0.25	0.5

APPENDIX B

WRITTEN MOUSE PRACTICE INSTRUCTIONS PROVIDED TO SUBJECTS

The purpose of the mouse practice facility is simply to allow you to become familiar with using this particular mouse, so that when you are engaged in the NEWFIRE sessions you will not be distracted from solving the NEWFIRE problem by the purely mechanical actions of manipulating the mouse.

A sample mouse practice screen is on the next page. The mouse practice screen consists of two windows, a large green one and to the right of it, a smaller white one. Both are divided into a grid. At intervals, a light-blue, numbered icon will appear in the green grid. You are to move that icon to the smaller blue grid. The icons are moved in the following manner.

-- Click once on the icon to be moved. The cursor will become a cross.

-- Place the cursor (cross) on the next available destination cell (in the blue field).

-- Click once. The icon will appear in that cell, and the cursor will again be an arrow.

The first icon you move must go in the upper left-hand most cell of the white destination grid. Each successive icon must be placed in the cell immediately to the right of the one just filled. When a row is full, the next icon goes in the left-hand-most cell of the next row. The order of the numbers on the icons is unimportant. That is, you may fill the top row with the sequence 1,3,2,6,5,4,8,12,10.

You are now ready to begin the mouse practice.

- o Move the cursor to the blue field on the right hand side of the screen.
- o Click the *right mouse button* once. A menu will appear.
- o Move the cursor down to highlight "mouse practice".
- o Click once with the *left mouse button*.

The mouse practice begins immediately.

After you have completed the mouse practice:

- o Ensure the proctor records your time score.
- o Click once with the *left mouse button* in the small blue square (with a diagonal yellow line) in the upper left corner of the screen.

APPENDIX C

NEWFIRE INSTRUCTIONS PROVIDED TO SUBJECTS

C1 Written instructions provided before beginning practice scenario(s)

INTRODUCTION.

The purpose of this experiment is to examine how people make decisions in complex dynamic environments. We will use a simulated fire-fighting environment called NEWFIRE. No experience or knowledge of fire-fighting is needed.

Below is a (green) area occupying the left and middle part of the computer screen from bottom to top. This is a map of a forest. The map is divided into 18 x 18 squares or cells, each representing several hectares of vegetation (1 hectare = 10,000 square meters or 2.5 acres).

The forest is monitored by an airplane. If the pilot observes fire in the forest, he/she will transmit the coordinates of the place or places where it burns. A cell containing ignited forest changes color from green to red on your map.

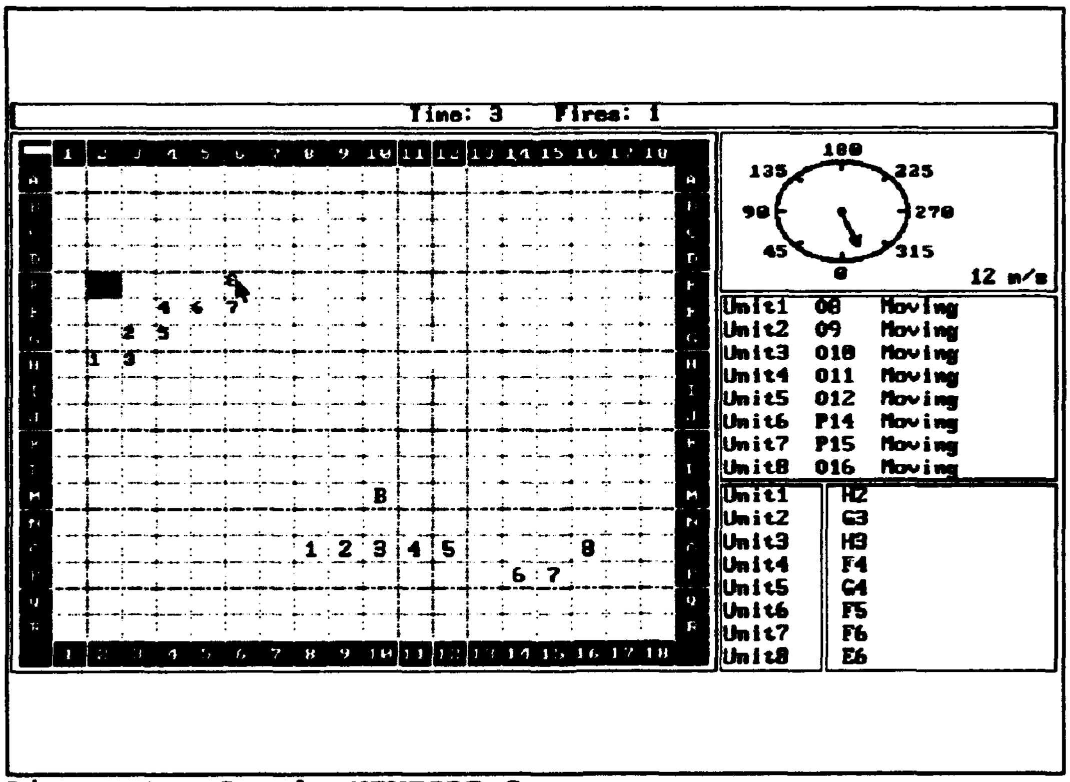

Figure 1. Sample NEWFIRE Screen

Some fires are confined to a single forest cell because they were discovered immediately. Others extend over a cluster of cells because they were ignited before the spotter plane arrived in the area.

In any of your sessions it is vital for you to prevent the fire from reaching a particular cell on the map. This cell is brown and has a B written on it. *B stands for base and marks out the place where you are situated. If the base is lost, the session will terminate immediately.*

You are to perform your fire fighting task by acting as a commander of eight fire fighting units. These are squads of forest rangers moving in Landrovers. The cells in which these resources are positioned are overlaid by an icon which you can click on with the mouse. The icon of a fire fighting unit shows the unit's identification number and changes color in accordance with the unit's activity. Two or more units may be in the same cell at the same time. If two or more units are in a cell, the icon displayed belongs to the unit that entered that cell last.

In the upper right corner of the screen you can read the direction and speed (in meters per second) of the wind. The arrow of the wind indicator points to the direction the wind is blowing toward. The numbers on the circular scale of the indicator can be used to read the compass direction the wind is blowing from. See Figure 2. (next page)

The middle panel to the right of the forest map is the Message Panel. Messages from the units are displayed here as text. This panel also lists the current location of each unit.

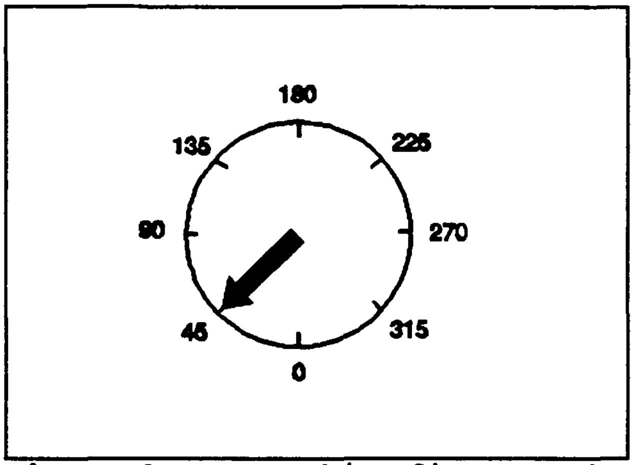

Figure 2. In this figure, the wind is blowing from the northeast. That is, a balloon released in the center of the forest map would travel to the lower left hand corner of the screen.

Fortunately, the fire fighting units are thoroughly trained on their job. They perform it according to a fixed schedule within the cells to which they have been commanded to go. The only thing you have to do is to deploy and redeploy the units. You may wish to direct a particular unit to a particular cell either because fire has been ignited within the cell, or because the forest in the cell is threatened by approaching fire. Whatever your intention is, the unit will take proper action when it

arrives at the destination. If the unit detects fire in its new position, it will start fighting the fire immediately. Otherwise the unit will send the message 'watching' and keep itself ready to fight any fire that may be ignited in the cell at a later time. When you begin a session, all fire fighting units are inactive.

<u>OPERATING INSTRUCTIONS.</u>

o TO MOVE A FFU:
  - -- Place cursor on FFU to be moved.
  - -- Click once with left mouse button. The cursor will now become a cross.
  - -- Place this cross on the cell you want the FFU to go to.
  - -- Click once with the left mouse button. The number of unit selected will appear in the upper left hand corner of the destination cell.

The unit will change color to purple to indicate it is travelling to its destination. Also, the message "MOVING" will appear in the message panel to the right of the forest map. The unit will not however appear to move until the next update.

o TO CHANGE THE DESTINATION OF A TRAVELLING FFU:
  - -- Place cursor on the purple icon of the <u>unit</u> itself, NOT the destination cell.
  - -- Click once with left mouse button. The cursor will now become a cross.
  - -- Place the cross on the new cell you want the FFU to go to.
  - -- Click once with the left mouse button. The number of unit selected will appear in the upper left hand corner of the new destination cell.

o TO STOP A TRAVELLING UNIT, AND KEEP IT WHERE IT IS:
  - -- Place cursor on the purple icon of the <u>unit</u> itself.
  - -- Double Click the left mouse button.

o IF TWO OR MORE FFU's ARE IN ONE CELL:
  - -- Move cursor to the selector pane in the lower right hand corner of the screen.
  - -- Click once on the line containing the unit you wish to move. The cursor will become a cross.
  - -- Place the cursor on the cell you want that FFU to move to. The FFU's number will appear in the upper left hand corner of the destination cell.

If you try to click on the icon of a unit that is not the only one in the cell, you will be prompted to make your choice of units in the selector pane.

Don't worry that the units may have to pass through burning forest in order to reach their destinations. The cells are large and never on fire everywhere at the same time, despite their uniform red color on the map.A unit begins fighting fire by mobilizing its resources: The forest rangers pull out their hoses and start the pump engine. Then the unit extinguishes the fire. When all fire has been extinguished, the unit demobilizes: The forest rangers dismantle their equipment and return to the Landrovers. The unit's icon is dark blue during these operations, which can be monitored by reading a message the unit sends to you each time it initiates a new action. Your screen is updated every hour on the hour. You cannot interrupt the fire fighting, nor can you speed it up by letting several units extinguish simultaneously in the same cell. If you place a unit in a cell in which another unit is fighting fire, the former unit will perceive that deployment as a parking maneuver and not begin to mobilize. You are allowed to provide a unit engaged in fire fighting with a new destination. The unit will obey the command as soon as it has extinguished and demobilized. A unit retained in its position after a completed fire fighting operation becomes inactive.

Once a fire fighting unit has extinguished a fire that cell will appear as a gray square when the unit is moved to a new positions. Unattended fires burn out after some time and leave black squares on the map. *The residue of the forest in these black or gray cells is not flammable and will <u>not</u> re-ignite.*

A trial terminates automatically when there is no more fire in the forest, or when you lose the base, whichever comes first. Only the portion of a cell that burns is counted as a loss.

The scenarios you will encounter in your sessions have been selected at random. The base and fire fighting units may be positioned anywhere on the forest map, and a fire may be displayed at any moment in any cell or cluster of cells.

In some scenarios another fire will be ignited after a while, but it also is possible that there will only be the initial fire to cope with. The potential secondary fire is always confined to a single forest cell.

The direction and speed of the wind vary from one scenario the other. The wind may remain constant throughout a trial, or it may shift more or less suddenly, but not more than once.

o TO REMOVE THE SCREEN DISPLAYED AFTER A COMPLETED TRIAL:

-- Move the cursor to the label bar uppermost on the screen.
-- Click with the right mouse button, or press the Del

key to open a menu that contains a line labelled 'close'.
-- Position the cursor on this line, and click with the left mouse button to execute the close command.

Good Luck!

You are now ready to perform a short practice scenario to familiarize your self with the NEWFIRE environment and its operation.

- o Open the menu by a *right mouse click* in the blue region of the screen.
- o Move the cursor down to highlight "NEWFIRE".
- o Click on "NEWFIRE" once with the *left mouse button*.
- o Insert the diskette provided to you by the proctor.
- o Click once with the *left mouse button* on the bar prompting you for the diskette.
- o Click once with the *left mouse button* on "Go Ahead".
- o Select "Proceed with your task number 1" by highlighting that bar and clicking once with the *left mouse button*.

The simulation begins immediately.

When you have completed the practice scenario, a yellow "GAME TERMINATED" banner appears across the top of the screen. Return to the start-up screen by clicking once on the small blue square in the upper left hand corner.

Ask the proctor for further instructions before continuing.

C2 Instructions given to subjects after completion of practice scenario(s)

You are now ready to begin the experiment scenarios.

o Select "Proceed with your task number 2" by clicking on that line with the left mouse button.

o After completing that scenario, return to the start-up screen as before, and select "Proceed with task number 3". Then perform task number 4, etc.

o After all tasks have been completed, the proctor will give you a short questionnaire to fill out. That will conclude the experiment.

Thank you very much. Your time and efforts are greatly appreciated.

APPENDIX D

OBJECTIVE AND COST INFORMATION PROVIDED TO SUBJECTS

D1 Objective information provided to the one objective group

Your mission is to put out all the fires without losing your base. In extinguishing the fire, you should **minimize the amount of forest area burned.**

Note that some fire-fighting units may not be as effective as others with regard to the speed with which they move, and the speed with which they put out a fire.

D2 Objective information provided to the two objective group. The order the objectives were presented was randomized within the group.

So far the cost of operating the fire-fighting units was not an issue. However, in the real world, these cost are constraints on decision-makers. This simulation takes that into consideration by accumulating costs at the rates listed below.

FFU Activity	Cost per Time Period
Inactive	No Cost
Watching	$ 1.00
Moving	$ 2.00
Mobilizing, Fighting Fire, or Demobilizing	$ 4.00

Your mission is to put out all the fires without losing your base. In doing this, you should

- o **minimize the amount of forest area burned.**
- o **minimize costs incurred by FFU's**

Both of these objectives are of equal importance.

Note that some fire-fighting units may not be as effective as others with regard to the speed with which they move, and the speed with which they put out a fire.

D3 Objective and cost information provided to the three objective group. The order the objectives were presented was randomized within the group.

So far the cost of operating the fire-fighting units was not an issue. However, in the real world, these cost are constraints on decision-makers. This simulation takes that into consideration by accumulating costs at the rates listed below.

FFU Activity	Cost per Time Period
Inactive	No Cost
Watching	$ 1.00
Moving	$ 2.00
Mobilizing, Fighting Fire, or Demobilizing	$ 4.00

Your mission is to put out all the fires without losing your base. In doing this, you should

- **extinguish the fire in as little time as possible**
- **minimize costs incurred by FFU's**
- **minimize the amount of forest area burned.**

All three of these objectives are of equal importance.

Note that some fire-fighting units may not be as effective as others with regard to the speed with which they move, and the speed with which they put out a fire.

APPENDIX E

QUESTIONS ANSWERED BY SUBJECTS

A1 Questions answered by all subjects.

1. Describe the general strategy you followed when deploying Fire Fighting Units (FFU's)?

2. Please try to elaborate on the thinking process you went through in making your decisions in this session. (Use the back of the page if necessary)

3. Describe how the goals you were given affected your strategy, or how you incorporated those goals in your strategy.

7. How clear were the instructions regarding the task?

1 2 3 4 5 6 7 8 9
Not at all Clear — Very Clear

8. To what extent was the information provided in the message panel (along the right hand side of the screen) helpful in making decisions?

1 2 3 4 5 6 7 8 9
Not at all Helpful — Very Helpful

9. To what extent was the report of time (across the top of the screen) helpful in making decisions?

1 2 3 4 5 6 7 8 9
Not at all Helpful — Very Helpful

10. To what extent was the report of cost (across the top of the screen) helpful in making decisions?

1 2 3 4 5 6 7 8 9
Not at all Helpful — Very Helpful

11. To what extent was the report of area lost (across the top of the screen) helpful in making decisions?

1 2 3 4 5 6 7 8 9
Not at all Helpful — Very Helpful

12. In the sessions you just completed, did you
a. Use the cost information (Y/N)?
b. If you did, please describe how you used that information.

13. Briefly describe any previous experience you have had with fire-fighting.

14. How interesting was the task you just performed?

1	2	3	4	5	6	7	8	9
Not at all Interesting								Very Interesting

15. How serious were <u>you</u> in performing the task?

1	2	3	4	5	6	7	8	9
Not at all Serious								Very Serious

16. How clear were the instructions regarding the task, generally?

1	2	3	4	5	6	7	8	9
Not at all Clear								Very Clear

17. How easy was the system to use?

1	2	3	4	5	6	7	8	9
Not at all Easy								Very Easy

18. How familiar are you with computers, generally?

1	2	3	4	5	6	7	8	9
Not at all Familiar								Very Familiar

19. How familiar are you with using direct manipulation devices (e.g. mouse, joystick)?

1	2	3	4	5	6	7	8	9
Not at all Familiar								Very Familiar

20. Please give me some information about yourself (in <u>absolute</u> confidence). At no time will your name appear in the results. The data will only be used in an aggregate statistical sense.

a. Curriculum:
b. Branch of Service:
c. Community
d. Sex:
e. Age:
f. Years of full time work experience:
g. How many years ago did you complete your undergraduate education:

21. Your general comments regarding the simulation:

A2 Additional questions answered by the two objective group

4. In executing the scenarios, describe how you weighted cost relative to area:

a. Substantially less than area
b. Somewhat less than area
c. Equally
d. Somewhat more than area
e. Substantially more than area

Any comments:

5. For each scenario, was the target cost given adequate to accomplish the task?

a. Scenario # 1

1	2	3	4	5	6	7	8	9
Not at all Adequate								Very Adequate

b. Scenario # 2

1	2	3	4	5	6	7	8	9
Not at all Adequate								Very Adequate

c. Scenario # 3

1	2	3	4	5	6	7	8	9
Not at all Adequate								Very Adequate

6. For each scenario, was the upper limit (ceiling cost) given adequate to accomplish the task?

a. Scenario # 1

1	2	3	4	5	6	7	8	9
Not at all Adequate								Very Adequate

b. Scenario # 2

1	2	3	4	5	6	7	8	9
Not at all Adequate								Very Adequate

c. Scenario # 3

1	2	3	4	5	6	7	8	9
Not at all Adequate								Very Adequate

A3 Additional questions answered by the three objective group

4a. In executing the scenarios, describe how you weighted cost relative to area:

a. Substantially less than area
b. Somewhat less than area
c. Equally
d. Somewhat more than area
e. Substantially more than area

4b. In executing the scenarios, describe how you weighted cost relative to time:

a. Substantially less than time
b. Somewhat less than time
c. Equally
d. Somewhat more than time
e. Substantially more than time

4c. In executing the scenarios, describe how you weighted area relative to time:

a. Substantially less than time
b. Somewhat less than time
c. Equally
d. Somewhat more than time
e. Substantially more than time

Any comments:

5. For each scenario, was the target cost given adequate to accomplish the task?

a. Scenario # 1

1	2	3	4	5	6	7	8	9
Not at all Adequate								Very Adequate

b. Scenario # 2

1	2	3	4	5	6	7	8	9
Not at all Adequate								Very Adequate

c. Scenario # 3

1	2	3	4	5	6	7	8	9
Not at all Adequate								Very Adequate

6. For each scenario, was the upper limit (ceiling cost) given adequate to accomplish the task?

a. Scenario # 1

1	2	3	4	5	6	7	8	9
Not at all Adequate								Very Adequate

b. Scenario # 2

1	2	3	4	5	6	7	8	9
Not at all Adequate								Very Adequate

c. Scenario # 3

1	2	3	4	5	6	7	8	9
Not at all Adequate								Very Adequate

LIST OF REFERENCES

Brehmer, B., "Dynamic Decision Making: Human Control of Complex Systems, *Acta Psychologica*, v. 81, pp. 211-241, 1992.

Brehmer, B., Loevborg, L., and Winman, A., *Learning the Time Constants of a Dynamic Task*, Working Papers in Cognitive Science and HCI, O. Ravnholt, (Ed.), Centre for Cognitive Science, University of Roskilde, Denmark, WPCS-92-6, 1992.

Brehmer, B., Loevborg, L., and Winman, A., *Cost Information in a Dynamic Decision Task*, Working Papers in Cognitive Science and HCI, O. Ravnholt, (Ed.), Centre for Cognitive Science, University of Roskilde, Denmark, WPCS-92-8, 1992.

Funke, J., "Solving Complex Problems: Exploration and Control of Complex Systems," in R.J. Sternberg, and P.A. Frensch (Eds.), *Complex Problem Solving: Principles and Mechanisms*, pp. 185-222, Lawrence Erlaum Associates, Inc., 1991.

Hogarth, R.M., "Beyond Discrete Biases: Functional and Dysfunctional Aspects of Judgmental Heuristics," *Psychological Bulletin*, v. 90, no. 2, pp 197 217, 1981.

Ketscher, L., "Knowledge Structure in a Computer-Simulated Environment," in H. Larsen and K.E. Petersen (Eds.), *Systems Analysis Department Annual Progress Report, 1991*, pp. 27-28, Risoe National Laboratory, Roskilde, Denmark, Risoe-R-612(EN), 1992.

Kirk, R.E., *Experimental Design: Procedures for the Behavioral Sciences*, Monterey, CA: Brooks/Cole, 1982.

Kleinmuntz, D.N., "Cognitive Heuristics and Feedback in a Dynamic Decision Environment," *Management Science*, v. 31, pp 680-702, 1985.

Kleinmuntz D., and Kleinmuntz B., "Systems Simulation: Decision Strategies in Simulated Environments," *Behavioral Science*, v. 26, no. 1, pp. 294-305, 1981.

Loevborg, L., and Brehmer, B., *NEWFIRE--A Flexible System for Running Simulated Fire-Fighting Experiments*, Risoe National Laboratory, Roskilde, Denmark, Risoe-M-2953, 1991.

Loevborg, L., and Brehmer, B., *New Facilities in NEWFIRE*, Working Papers in Cognitive Science and HCI, O. Ravnholt, (Ed.), Centre for Cognitive Science, University of Roskilde, Denmark, WPCS-92-8, 1992.

Mackinnon, A.J., and Wearing, A.J., "Complexity and Decision Making," *Behavioral Science*, v. 25, pp. 285-296, 1980.

SAS/STAT, *Guide for Personal Computers*, Version 6, Cary, NC: SAS, 1987.

Sengupta, K., and Abdel-Hamid, T., "An Investigation of Alternative Feedback Strategies in Dynamic Decision Making," *Management Science*, v. 39, no. 4, pp. 411-428, 1993.

Winer, B.J., *Statistical Principals in Experimental Design*, New York, NY: McGraw-Hill, 1971.

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